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Introduction

Winter cereal rye continues to be promoted as a viable cover crop within Iowa for corn and soybean production systems. Several environmental benefits accrue with use of cover crops, including reduction of nitrate in drainage water, soil erosion control, and reduced phosphorus (P) runoff loss. In the Iowa Nutrient Reduction Strategy, a rye cover crop is estimated to reduce nitrate-N concentration by 31%, a sizeable impact. However, questions remain about rye cover crop effects on corn nitrogen (N) fertilization requirement, N supply from the cover crop, and crop yield. To help answer these questions, a series of studies were conducted to evaluate corn economic optimum N rate (EONR), rye cover crop degradation and N recycling following termination, rye shoot and root biomass and nutrient composition, corn and soybean yield, and agronomic practices to improve corn yield in a rye cover crop system.

Methods summary

Corn nitrogen rate fertilization with a rye cover crop

- Five locations at Iowa State University research farms, crop years 2009-2013 [Ag Engineering/ Agronomy Farm (AEA), Ames; Armstrong Memorial Research Farm (SW), Lewis; Northeast Research Farm (NE), Nashua; Northwest Research Farm (NW), Sutherland; and Southeast Research Farm (SE), Crawfordsville]. The first year for the Northwest farm site was 2011.
- No-till corn-soybean rotation.
- With and without a rye cover crop (Wheeler variety) drilled after crop harvest at one bu/acre.
- Rye terminated with glyphosate in the spring at least 7 days before corn planting and at or within 7 days before soybean planting (as weather and soil conditions allowed). Termination date intended to not delay normal corn and soybean planting.
- Six N fertilizer rates (0 to 200 lb N/acre) injected early sidedress as urea-ammonium nitrate solution (UAN).
- Aboveground rye vegetation collected at time of termination for biomass and N uptake.
- Soil sampled for profile nitrate-N at time of rye termination and late-spring (with no N applied).
- Corn and soybean grain yield.
- Optimal N rate determined from corn grain yield N rate response.

Rye cover crop biomass degradation and nitrogen cycling

- Four locations from 2010-2011 (same locations used in the N rate fertilization study).
- Rye following corn at three N rates (0, 120, and 200 lb N/acre) and following soybean.
- Rye vegetation collected at termination, placed in mesh bags left on the no-till soil surface, and collected at 3, 9, and 15 weeks after termination.
- Remaining rye material analyzed for dry matter (DM), carbon (C), and N.

Rye cover crop shoot and root composition

- Ames location from fall 2014 to spring 2015.
- Rye (Wheeler) drilled after corn and soybean harvest.
- Three N rates (previously applied to corn in the spring).
- Root ingrowth tubes installed at 0-2 feet (following corn) and 0-1 foot (following soybean) depths to determine rye root growth.
- Ingrowth tubes harvested in the spring at rye termination (April 29 following soybean and May 8 following corn).
- Rye shoot and root material analyzed for biomass DM production, C, and N.

Agronomic practices to enhance corn yield

- Four locations in Iowa from 2014-2016 (same locations used in the N rate fertilization study).
- Corn-soybean rotation.
- No-till and rye cover crop history since 2008.
- With and without rye cover crop (Wheeler).
- Rye aerial broadcast into standing soybean before leaf drop at 1.5 to 2 bu/acre.
- Rye cover crop only following soybean.
- Planned rye termination at approximate 6-8 inch rye height.
- Aboveground rye vegetation collected at time of termination for biomass and N uptake.
- Tillage systems: no-till and spring disk tillage for corn; no-till and fall chisel plow/spring disk for soybean.
- Rye termination with glyphosate. Tillage after rye termination.
- Corn planting at least 2 weeks after rye termination.
- Corn planted with and without 30 lb N/acre starter (2 inches beside x 2 inches below the corn seed furrow).
- Main N fertilizer applied sidedress as injected UAN (total 150 lb N/acre).
- Corn plant population and height determined at the V6 growth stage.

Results and discussion

Corn nitrogen rate fertilization with a rye cover crop

Across the five years of the study, rye aboveground biomass DM at termination in the spring following corn ranged from a yearly mean of 440 lb/acre to 1220 lb/acre. There was an N rate effect (N fertilizer applied to the corn in the prior spring), with across the last four years of study rye biomass mean of 845, 985, and 1220 lb/acre for the zero, 120 and 200 lb N/acre rates, respectively. The mean rye biomass following soybean was 580 lb DM/acre. The mean amount of N in the rye aboveground biomass was 16, 21, and 28 lb N/acre for the zero, 120, and 200 lb N/acre rates, respectively, following corn and was 18 lb N/acre following soybean. The amount of rye biomass and N uptake varied between locations and years as influenced by planting date, termination date, prior-year N rate to corn, and fall and spring weather conditions. Overall, the amount of N uptake by the rye was low (mean of 20 lb N/acre), and by individual treatment, location, and year a minimum of 2 lb N/acre and a maximum of 62 lb N/acre.

The rye cover crop did reduce profile nitrate-N at the time of termination, as it should, with an average

14 lb N/acre lower profile nitrate-N (top two feet of soil) with rye compared to no rye. By the time of late spring sidedress nitrate-N sampling, there was no difference in the top two feet of soil.

Soybean grain yield was not affected positively or negatively by the rye cover crop planted after corn (Table 1). Across all locations and years, corn yield at the EONR (YEONR) was 5% lower with the rye cover crop compared to no rye cover crop (Figure 1). As the amount of rye biomass produced increased, the reduction in corn yield increased (Figure 2), however, there was considerable variability in that relationship. The yield response to N fertilizer rate was the same with and without the rye cover crop, and with only a 6 lb N/acre rate difference in the EONR. The corn yield was less affected by the rye when adequate N was applied (at the EONR) than with no N or the lowest N rates (Figure 1).

Table 1. Soybean grain yield with and without rye cover crop, 2009-2013.

Cover Crop	AEA	SE	SW	NE	NW
			bu/acre		
With rye	54.4a†	58.5a	58.5a	61.2a	63.3a
Without rye	53.5a	59.0a	58.1a	62.4a	62.8a

† Yields at a location followed by the same letter are not different, $p \leq 0.10$.

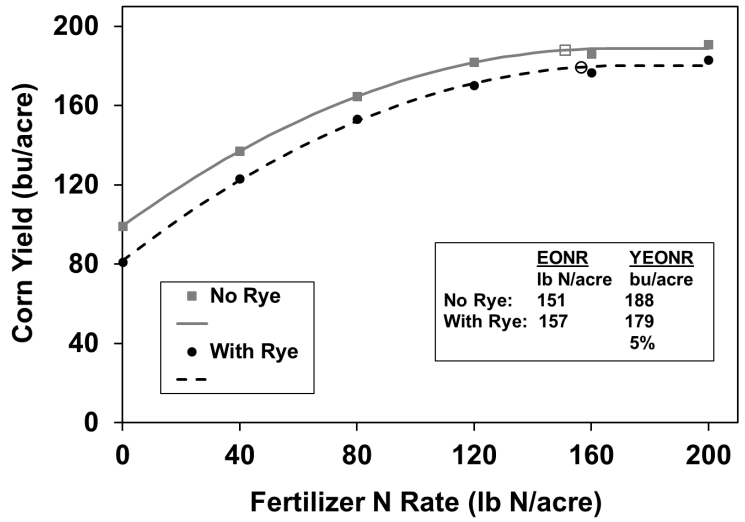

Figure 1. Effect of a rye cover crop on corn yield and N response across a series of N rates (EONR, economic optimum N rate; YEONR, yield at the economic optimum N rate), across locations, 2009-2013.

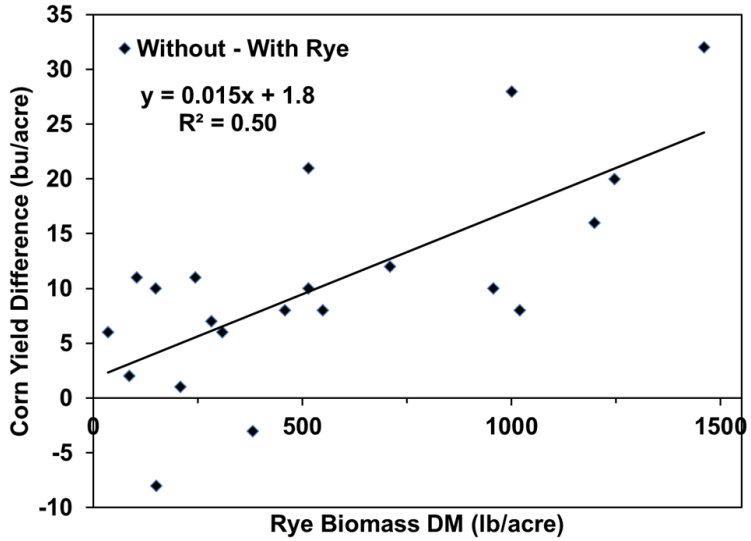

Figure 2. Relationship between the amount of rye biomass dry matter (DM) produced before corn planting and the difference in corn yield between with and without the rye cover crop (corn yield without rye minus yield with rye), 2009-2013.

Rye cover crop biomass degradation and nitrogen cycling

The amount of rye cover crop biomass and associated N remaining after termination declined over time in a curvilinear trend (Figure 3). That means the rye degradation was faster shortly after termination and slowed over time. The rye degradation was faster with rye following soybean than following corn. That could be due to more rye-soil contact between the mesh bags with the no-till soybean stubble than corn stalks, and/or due to the rye material carbon:nitrogen (C:N) ratio being greater following corn than soybean. By 105 days after termination, approximately 60% of the original rye N amount following corn (10-14 lb N/acre) and 77% of the N following soybean (20 lb N/acre) was gone from the mesh bags. These results indicate that N taken up by the rye will recycle after termination, but the process is not rapid and depending on the degradation rate will not be complete for some time. The early recycling may be a reason the profile soil nitrate-N was the same with and without rye by the late spring.

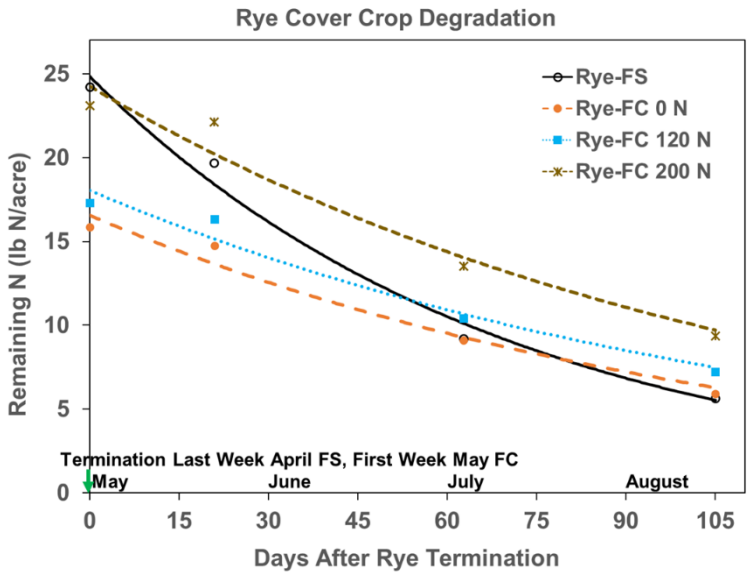

Figure 3. Rye biomass N remaining with time after rye cover crop termination (FS, following soybean and FC following corn; 0 N, 120 N, and 200 N the lb N/acre fertilizer rate applied to the prior year corn), 2010-2011.

Rye cover crop shoot and root composition

At termination in the spring, the rye cover crop aboveground shoots accumulated twice the amount of biomass DM, five times the amount of N, and a C:N ratio that was two to three times lower than the roots (Table 2). This indicates more partitioning of DM and N to the rye aboveground biomass. As most of the N was contained in the shoot material, measure of the aboveground biomass N can provide a reasonable measure of total rye cover crop N uptake. With the high C:N ratio of the root material, inorganic-N from the soil or degrading shoot material could be immobilized during root degradation (C:N ratios > approximately 30:1 will result in net immobilization; and < 20:1 net mineralization), thus reducing plant-available N recycling to the next annual corn or soybean crop. This may help explain the lack of difference in corn EONR found in previous studies (see above).

Table 2. Rye cover crop shoot and root composition, 2015.

Plant Component	Biomass	Nitrogen	C:N Ratio
	lb DM/acre	*lb N/acre*	
Following Corn			
Shoot	983a†	18a	23b
Root	463b	4b	52a
Following Soybean			
Shoot	1096a	26a	16b
Root	573b	5b	47a

† Letters in a column and prior crop indicate significant difference ($p \leq 0.10$) (C:N, carbon to nitrogen ratio).

Agronomic practices to enhance corn yield

Changing rye cover planting from drilling after soybean harvest to aerial inter-seeding into standing soybean resulted in greater variability in rye stand establishment and biomass production. This especially occurred with dry fall conditions. Also, with the no-till corn/soybean system, there could be limited seed-soil contact decreasing successful germination with the surface seed placement. The plan was to terminate the rye cover crop at 6-8 inches in height, which was achieved. That planned height at termination would also limit biomass accumulation and N uptake, and as compared to the previous N rate fertilization study. Across the four locations and three years of study, the amount of rye aboveground biomass was 615 lb DM/acre with the till system and 524 with no-till. Also, the total N uptake was only 16 lb N/acre with tillage and 14 lb N/acre with no-till.

Plant population was higher with no-till, but not different with or without starter or with or without the rye cover crop (Table 3). The corn height at the V6 growth stage was slightly taller with tillage, starter, and no rye cover crop. The corn yield was 6 bu/acre greater with the tilled system compared to no-till, no difference with the starter N (30 lb N/acre) application, and 4 bu/acre lower (2%) with the rye cover crop. Use of tillage after rye termination was the only single agronomic practice that enhanced corn yield following the cover crop.

Table 3. Corn population, plant height, and grain yield, 2014-2016.

Practice		V6 Population	V6 Height	Yield
		plants/acre	*inch*	*bu/acre*
Tillage	Till	32,500b†	24a	209a
	No-till	33,500a	22b	203b
Starter	Starter	33,000a	23a	207
	No starter	33,000a	22b	205
Cover Crop	With rye	33,000a	22b	204b
	No rye	33,000a	23a	208a

† Letters indicate significant difference ($p \leq 0.10$). No interaction between practices. Results across four locations.

Summary

- Rye cover crop biomass production was influenced by fall seeding date, prior crop, prior N rate applied to corn, fall and spring weather conditions, and date of termination. And generally influenced more than location in the state.
- Rye cover crop N uptake was small (mean of 20 lb N/acre) and related to the relatively low biomass production; with a range of 2 to 62 lb N/acre across locations and years.
- Soil nitrate-N was reduced at the time of termination, but not a large amount at 14 lb N/acre.
- Soybean yield was not affected by the rye cover crop, no matter the amount of rye DM produced or time between rye termination and soybean planting.
- Corn grain yield was lower with the rye cover crop (5%), with more yield reduction as the amount of rye DM at termination increased.
- The optimal N fertilization rate was not different between with and without the rye cover crop. Therefore, the current suggest N rates from the Corn Nitrogen Rate Calculator can be used when corn follows a rye cover crop.

- Rye recycling occurred following termination, but took time. After 105 days, 77% of rye N uptake following soybean and 60% following corn was gone from the rye material. It could be assumed that N returned to the soil as inorganic-N, but was not measured.
- Rye cover crop shoot biomass (67% of plant C) was twice the root biomass.
- Rye cover crop shoot N content (83% of plant N) was five times the root N.
- The rye root C:N ratio was considerably higher than shoot C:N ratio; 47-52:1 for root material and 16-23:1 for shoot material. The root C:N ratio indicates potential N immobilization with root degradation, which could influence net availability of plant available N from degrading rye cover crop.
- Of the agronomic practices to enhance corn yield following the rye cover crop, only tillage (compared to no-till) improved corn yield. A higher starter N by itself did not influence yield, even though the main N was sidedress applied. However, with the combined tillage, starter N, and rye termination when small, the corn yield difference between with and without the rye cover crop was only 2% -- an improvement over the previous rye cover crop study.

Acknowledgements

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